

PROGRESS REPORT

Engineering Properties of Subsea Permafrost

Submitted to  
U.S. Department of Interior  
Minerals Management Service  
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## PROGRESS REPORT

- I. TITLE: Engineering Properties of Subsea Permafrost.
- II. PRINCIPAL INVESTIGATORS: Edwin J. Chamberlain/Paul V. Sellmann.
- III. OBJECTIVE: To assess the strength of sediments unique to the arctic offshore environment and the effects on engineering structures.
- IV. PURPOSE: To provide a basis for the U.S. Department of Interior Minerals Management Service to devise requirements for the design and inspection of bottom-founded structure in the Alaskan Beaufort Sea. The specific purpose of this study is to evaluate the effects of seawater on frost heave, the shear strength of saline sediments at a freezing boundary, and the effect of the angle between the shear plane and the freezing plane on the shear strength of frozen saline soils. Another task was to analyze fundamental engineering properties of core obtained from the Beaufort Sea.
- V. PROGRESS: All of the laboratory work proposed under this study is complete with the exception of analysis of the engineering properties of core from the Beaufort Sea. This core was to be obtained by the USGS Marine Geology Branch from a drill ship in 40 to 50 meters of water during the open water season of the summer of 1983. However, ice conditions in the Beaufort Sea prevented the drill ship from gaining access to the drill sites and, thus, the core are not available. On February 17, 1984 we informed the Minerals Management Service that core would not be available and requested that the work be reprogrammed to study seasonal freezing processes in the Beaufort Sea. That work is presently in progress. A continuation proposal will be submitted at a later date.

The following summarizes the work performed. A more detailed technical report will be submitted in draft form shortly.

## VI. RESULTS:

### A. Frost Heave of Saline Soils.

Knowledge of frost heave and ice segregation processes in saline soils is important to understanding the potential frost action hazards to structures in the Beaufort Sea offshore environment. Much is known about the frost susceptibility of soils containing fresh water. In most cases, design criteria and engineering judgement allow the engineer to make safe designs. However, little is known about freezing processes in soils containing salts in their pore fluid; in particular, sea water.

Laboratory tests were conducted to compare frost heave of two soil types saturated with distilled water and seawater.

In the first series of tests, frost was propagated through the upper third of the samples and then the boundary temperatures were held constant to free the growth of segregated ice. Figures 1, 2, 3, and 4 show that the frost heave and ice segregation were much larger for the distilled water case. The amount and rate of frost heave was nearly 60% lower in the sea water case for both soil types. The effect of the salts in sea water on the ice

segregation in the clay were most dramatic (Figures 1 and 2) with the seawater completely suppressing the development of large ice lenses.

A second series of freezing tests was conducted at a constant frost penetration rate with the same materials and similar reductions in frost heave were observed.

#### B. Shear Strength in and near the Freezing Zone.

Knowledge of the shear strength in and near the freezing zone in saline soils is necessary to evaluate the capacity of offshore geotechnical structures (e.g. artificial islands) to resist the forces of sea ice. While it is known that the petroleum and gas industry is sponsoring work in this area, no studies of the shear strength of the freezing zone in saline soils have been reported.

Laboratory, direct shear studies were conducted on the same two test soils during their freezing with distilled water and seawater. Figures 5 and 6 show the test results. In all cases the peak shear strength  $\tau$  is plotted versus the temperature  $T$  at the shear plane. For the clay<sup>sp</sup> (Figure 5), the effect of seawater<sup>sp</sup> appears to be primarily to shift the  $\tau - T$  curve an amount approximately equal to freezing point depression of the seawater (  $-2^{\circ}\text{C}$ ). For the sand (Figure 6), this is not the case as the curves for the seawater and distilled water cases strongly diverge with decreasing temperature. The development of shear strength in and near the freezing zone in the sand is greatly reduced by the salts in the seawater.

It may be possible to explain the difference in shear strength in terms of unfrozen water content for both of the soils. These tests are presently underway and the results will be reported in the project technical report.

#### C. Shear Strength Anisotropy in Frozen Soils.

Information on the effect of the angle between the shear and freezing planes on the strength of frozen soils is also necessary to evaluate the capacity of artificial islands to resist the forces of sea ice. This is particularly important in determining slope stability where failures can occur across the discontinuities left by unidirectional freezing. No studies of this nature have been reported in the literature.

Laboratory direct shear tests were conducted at angles  $\alpha$  of  $0^{\circ}$ ,  $30^{\circ}$ ,  $60^{\circ}$  and  $90^{\circ}$  to the freezing plane for both the sand and silt soils for both seawater and distilled water cases. Figure 7 shows that for the clay the shear strength  $\tau_{\alpha}$  increases considerably ( $\approx 300$  kPa) with increasing  $\alpha$  for the distilled water case, but has only a small effect ( $\approx 50$  kPa) for the seawater case. For the sand, Figure 8 shows that  $\tau_{\alpha}$  varies by approximately 100 kPa for both the seawater and distilled water cases.

This series of tests also showed that the  $\tau$  is also a function of density and normal stress and that empirical equations can be used to predict shear strength for both the seawater and freshwater cases.

## VII. CONCLUSIONS:

- 1) Soils containing seawater heave considerably less than freshwater soils. The reduction in frost heave was more than 60% for the two soils studied.
- 2) Shear strength development in the freezing zone is greatly affected by seawater, particularly in the case of sands. The shear strength reduction in clays may be accounted for by the freezing temperature shift due to the salts in sea water. However, the reduction in shear strength for sandy soils can probably be accounted for only by considering the increase in unfrozen water content caused by the sea salts.
- 3) The shear strength of frozen soils is anisotropic, the shear strength generally increasing with increasing angle between the shear and freezing planes. The magnitude of the changes were greatest for the distilled water-clay case and least for the seawater-clay case.

## VIII. RECOMMENDATIONS:

It is recommended that shear strength studies continue to include cases of higher surcharge during freezing. It is also recommended that the effects of seasonal freezing of sea bed sediments be studied both in the laboratory and in the field. A proposal detailing the suggested research will be submitted later this month.

## IX. REPORTS:

The paper "Frost heave of saline soils" was presented at the 4th International Conference on Permafrost in Fairbanks, Alaska in July, 1983. Two other conference papers are in preparation. The report "Shear strength in the zone of freezing in saline soils" will be presented at the ASCE Specialty Conference, ARCTIC '85 in March, 1985. The report "Anisotropic shear strength of saline and fresh water soils" will be presented at the 4th International Conference on Ground Freezing in August 1985. In addition, a comprehensive technical report is being prepared for DOI, Minerals Management.

## X. FUNDING SUMMARY:

Funds expended FY84	88,892
Funds carried over to FY85	4,623

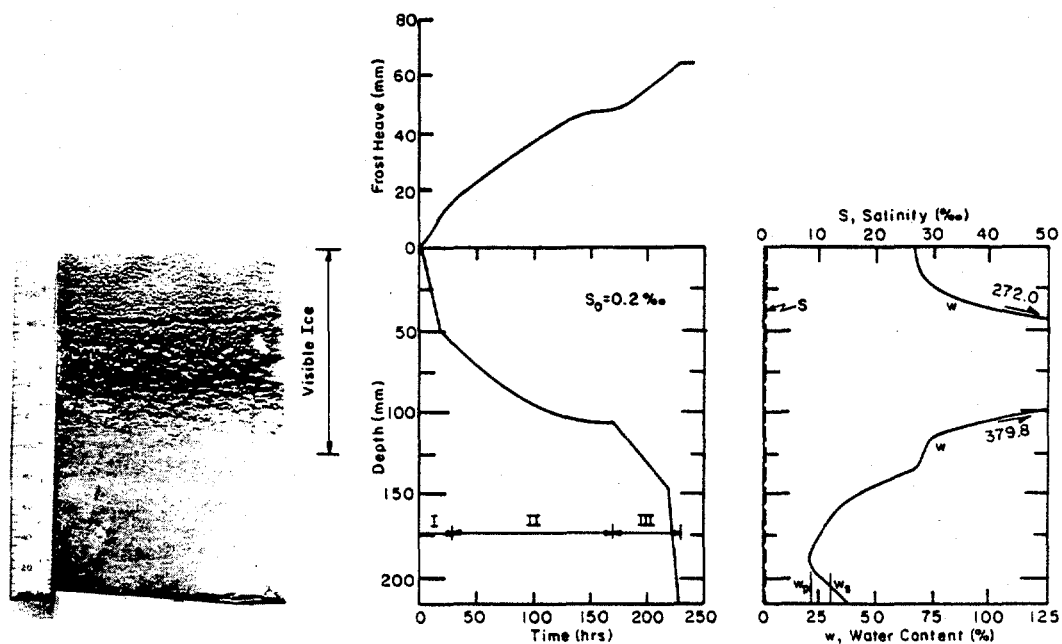


Figure 1. Freezing test results for the clay saturated with distilled water. Natural salinity  $S_0$  is approximately 0.2‰.

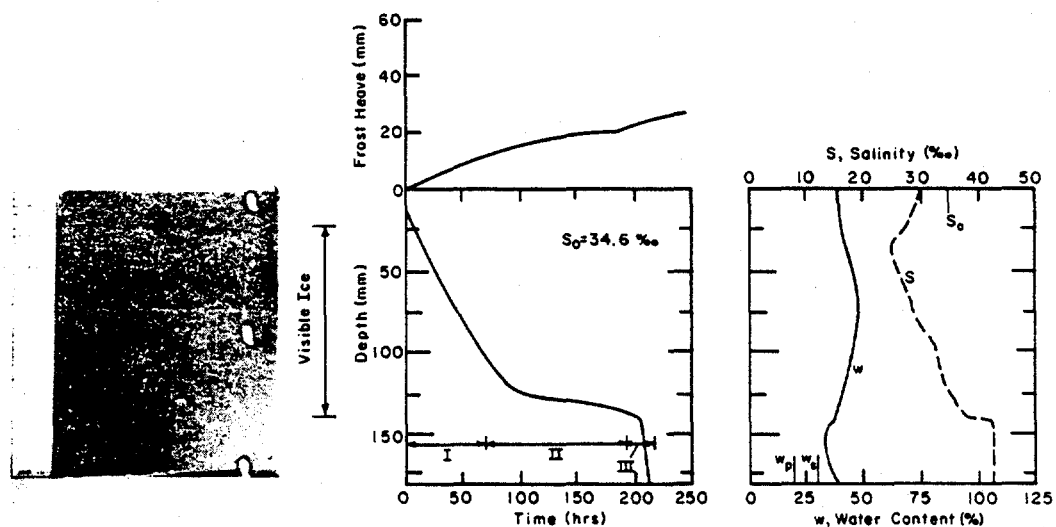


Figure 2. Freezing test results for the clay saturated with seawater. Initial salinity  $S_0$  is approximately 34.6‰.

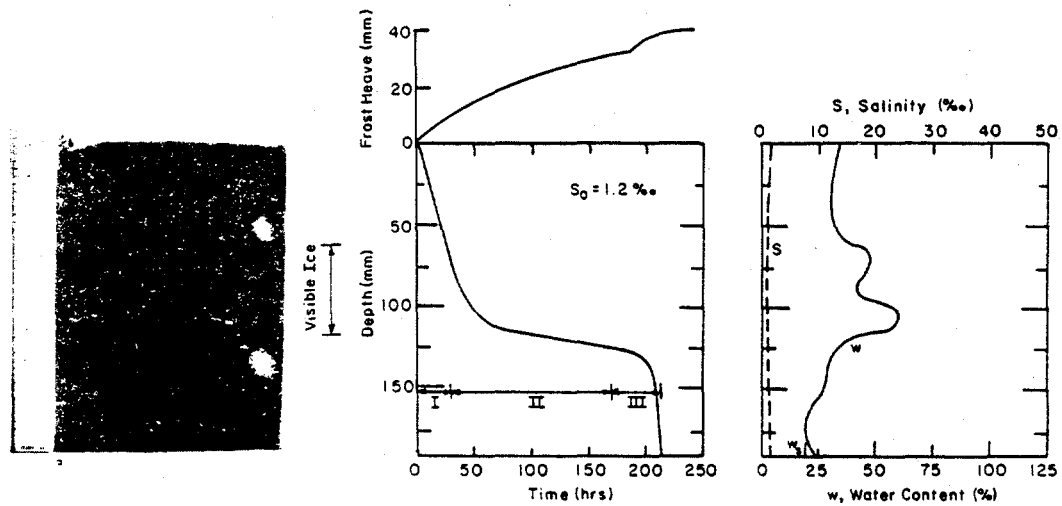


Figure 3. Freezing test results for the sand saturated with distilled water. Natural salinity  $S_0$  is approximately 1.2‰.

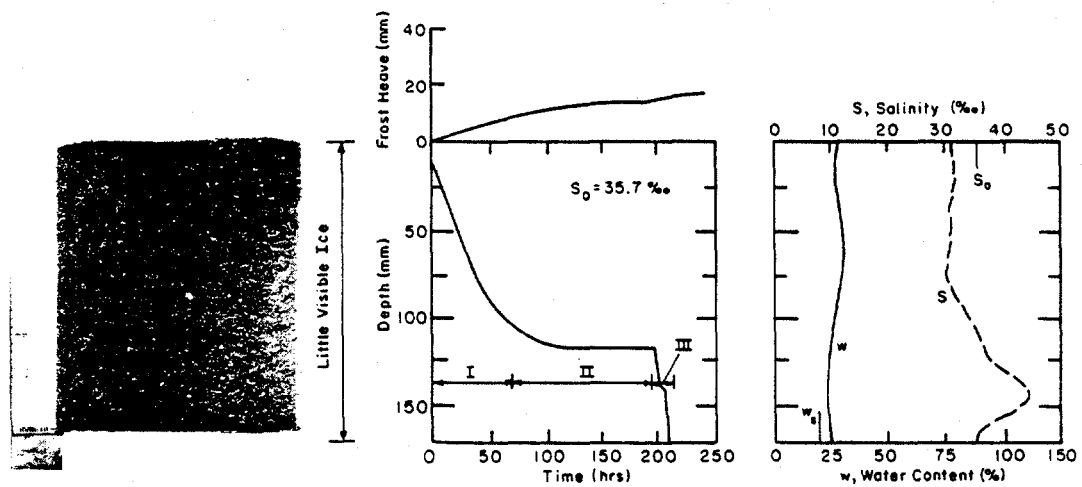


Figure 4. Freezing test results for the sand saturated with seawater. Initial salinity  $S_0$  is approximately 35.7‰.

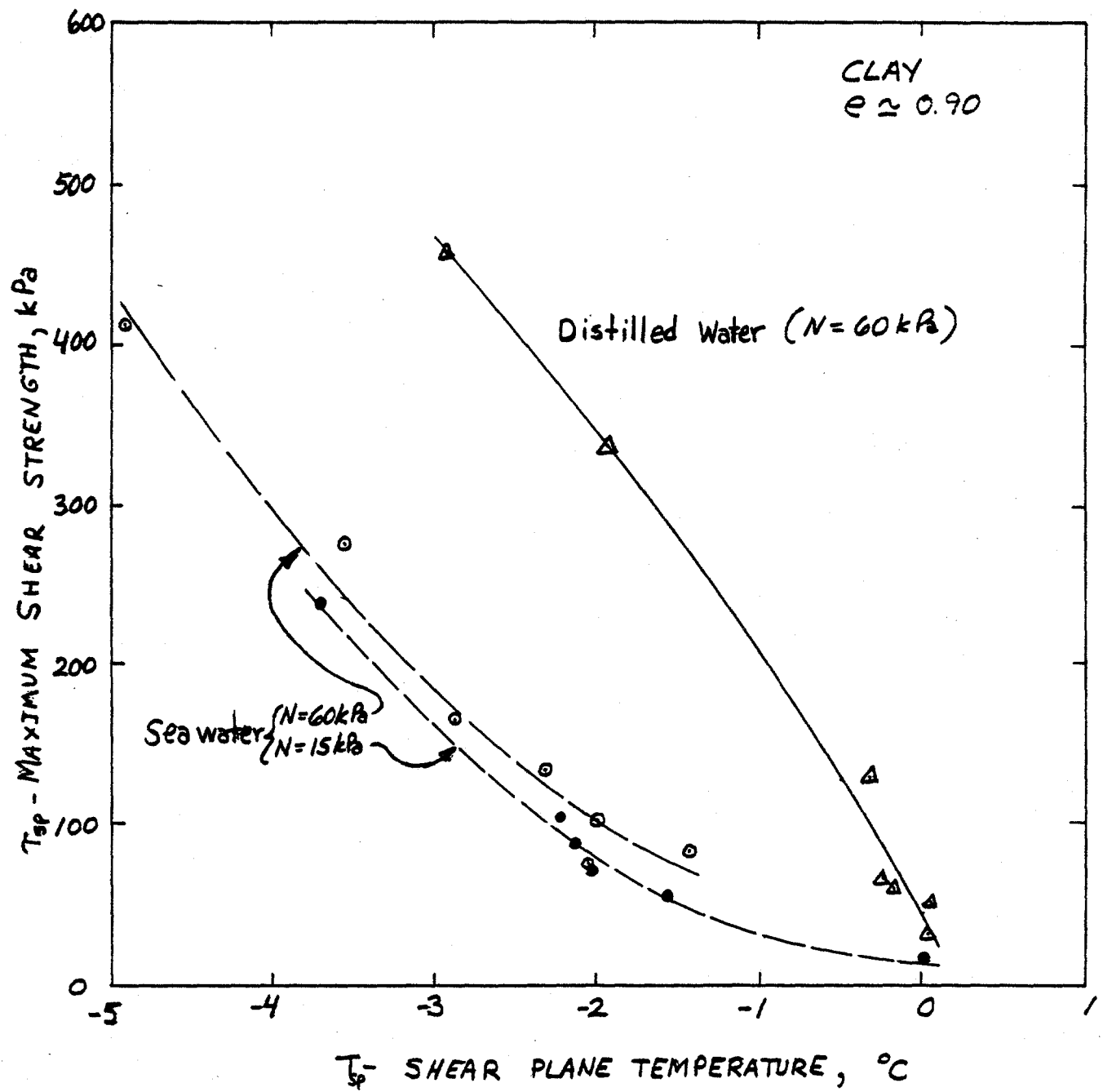


Figure 5. Shear strength of the clay in the freezing zone.

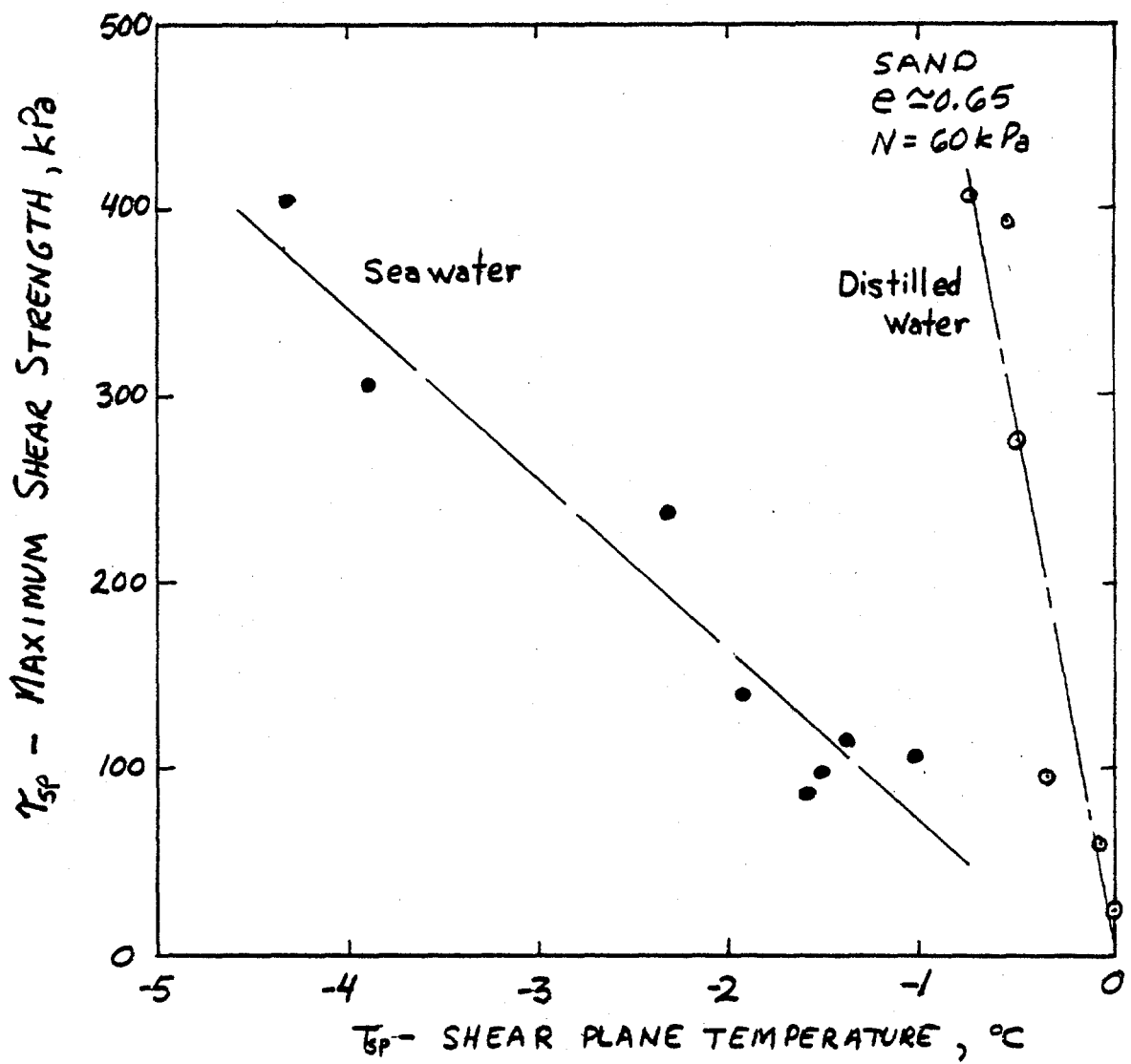


Figure 6. Shear strength of the sand in the freezing zone.

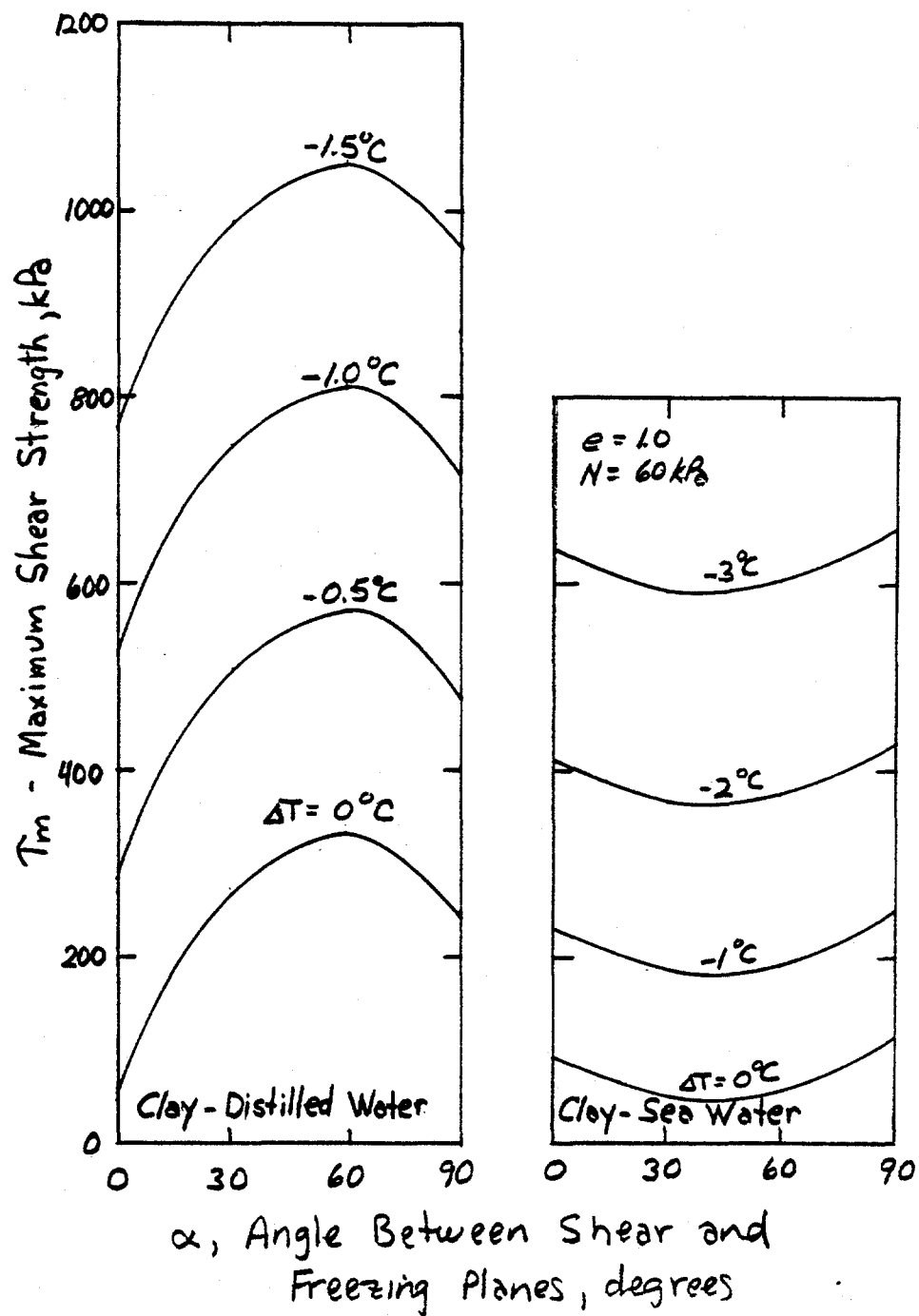


Figure 7. Shear strength anisotropy for the clay.

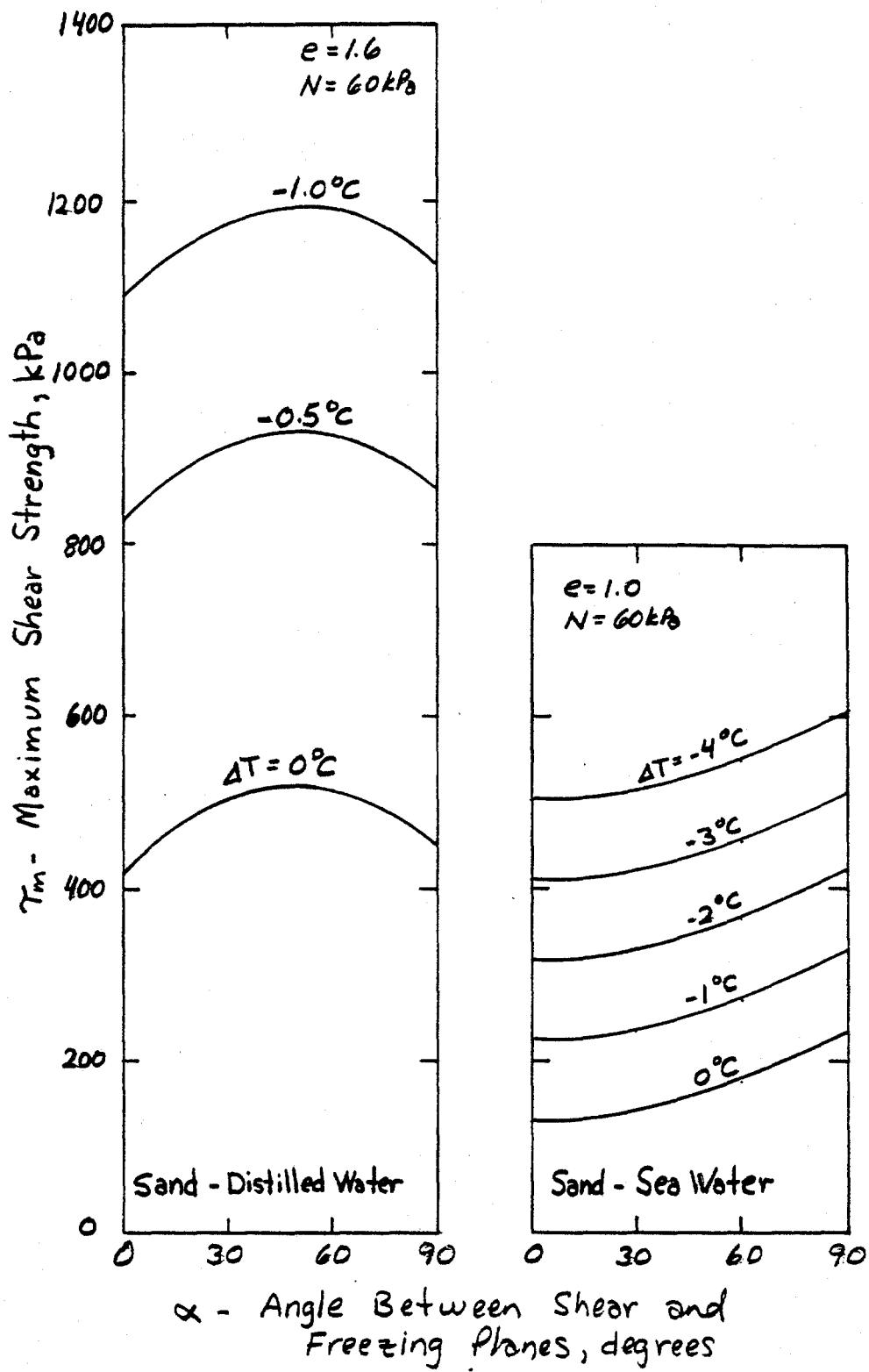


Figure 8. Shear strength anisotropy for the sand.